The Role of the Tropics in Producing the Exceptional Warmth over Eurasia and North America during January through March of 2020

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Heat Waves: Mechanisms, Predictability, and Prediction
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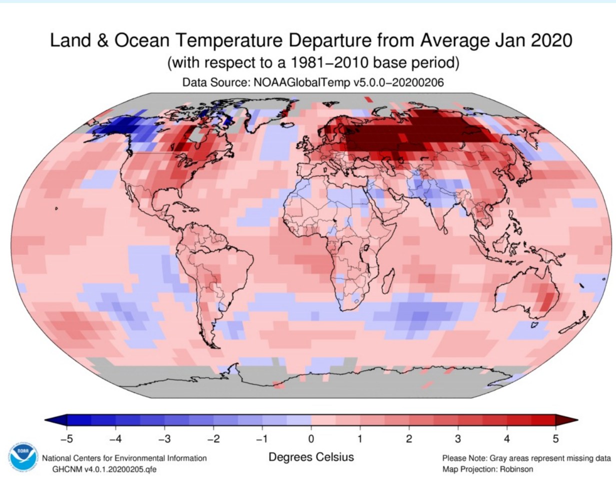
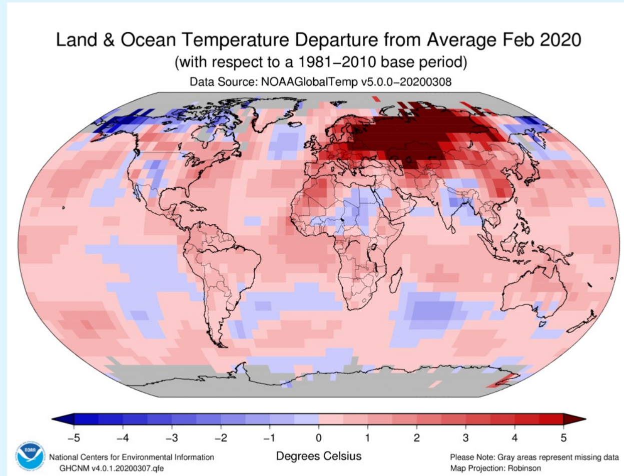
Overview: JFM 2020

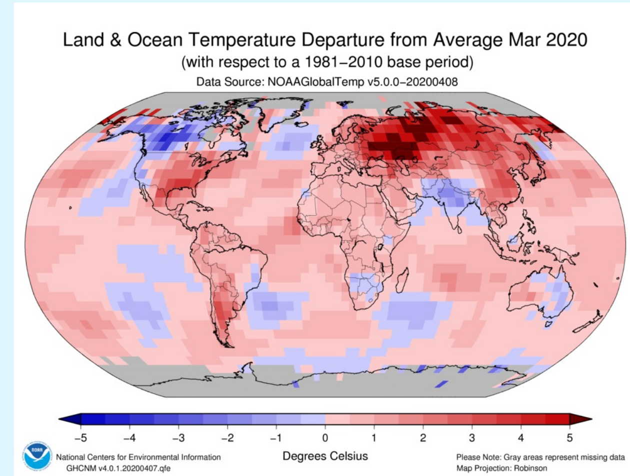
Jan



Feb



Mar



The January through March average temperature anomalies over Europe (+3.20 °C) and Asia (+3.66 °C) were the **highest in the 111-year record** (NOAA).

AO: record positive JFM index (since 1950)
NAO: near record positive JFM index (exceeded only twice in the last 70 years)
PNA: near record negative index for March (exceeded only once since 1950)

2020 Indices (NOAA/CPC)

	Jan	Feb	Mar
AO	2.42	3.42	2.64
NAO	1.34	1.26	1.01
PNA	-0.24	0.17	-2.17

What maintains the atmospheric modes (AO, NAO and PNA) well beyond their typical sub-monthly time scales?

We employ a regional "**replay**" approach in which simulations with the NASA GEOS AGCM are constrained to remain close to MERRA-2 over specified regions of the globe.

Schematic of NASA GEOS AGCM in replay mode

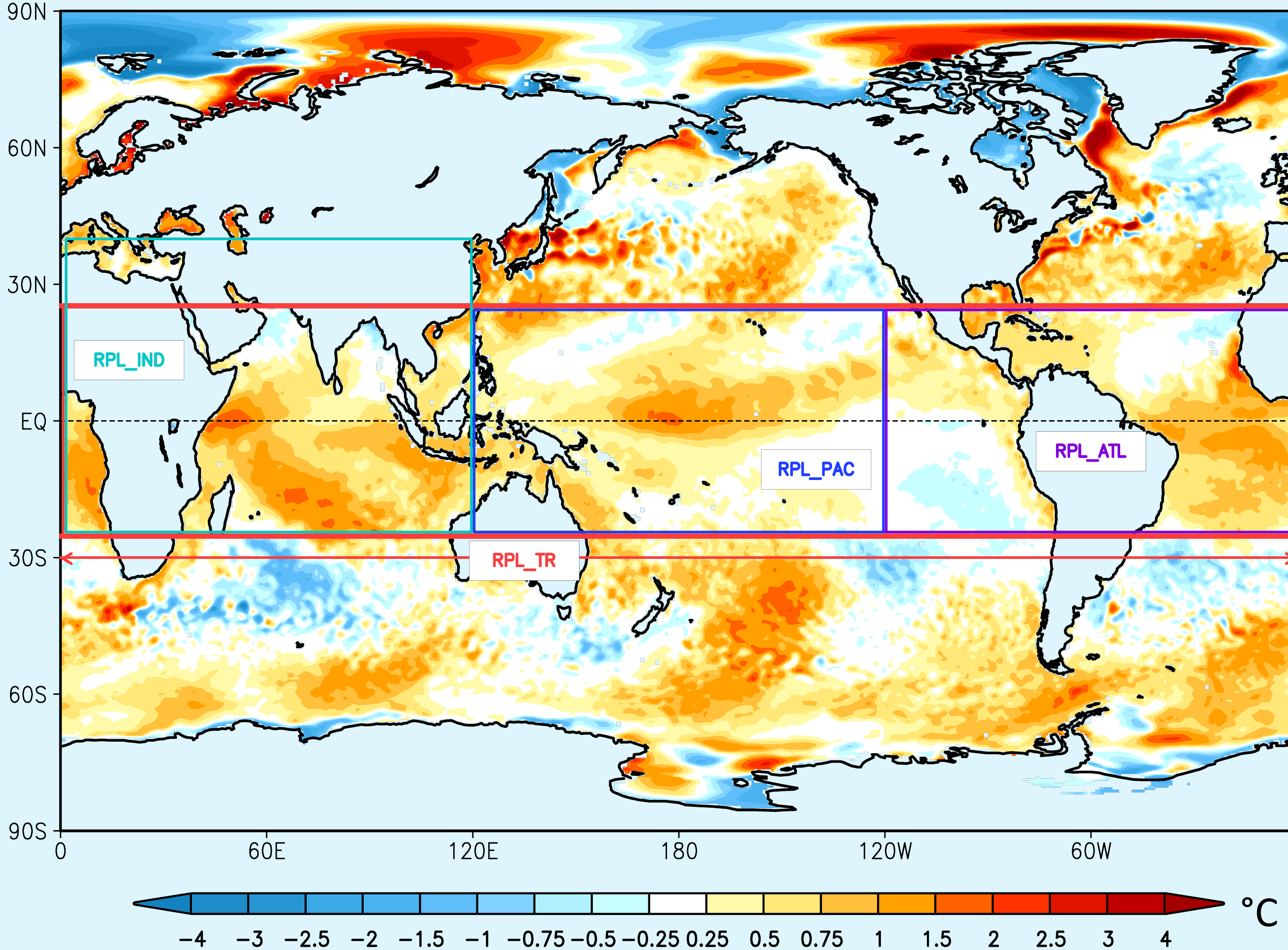
$$\frac{\partial x}{\partial t} = f(x) + \Delta x$$

Analysis increments are applied over limited regions of the globe,
$\Delta x = (\text{analysis} - \text{forecast})/6\text{hrs}$

Replay Experiments with GEOS AGCM

Name	Time period	Replay region	Ensemble members
NORPL	11/30/2018 – 06/30/2020	none	90
RPL_TR	11/30/2018 – 06/30/2020	Tropics: 25°S-25°N	90
RPL_PAC	11/30/2018 – 06/30/2020	Pacific Ocean region (25°S-25°N, 120°E-120°W)	90
RPL_ATL	11/30/2018 – 06/30/2020	Atlantic Ocean region (25°S-25°N, 120°W-0°)	90
RPL_IND	11/30/2018 – 06/30/2020	Indian Ocean region (25°S-40°N, 0-120°E)	90

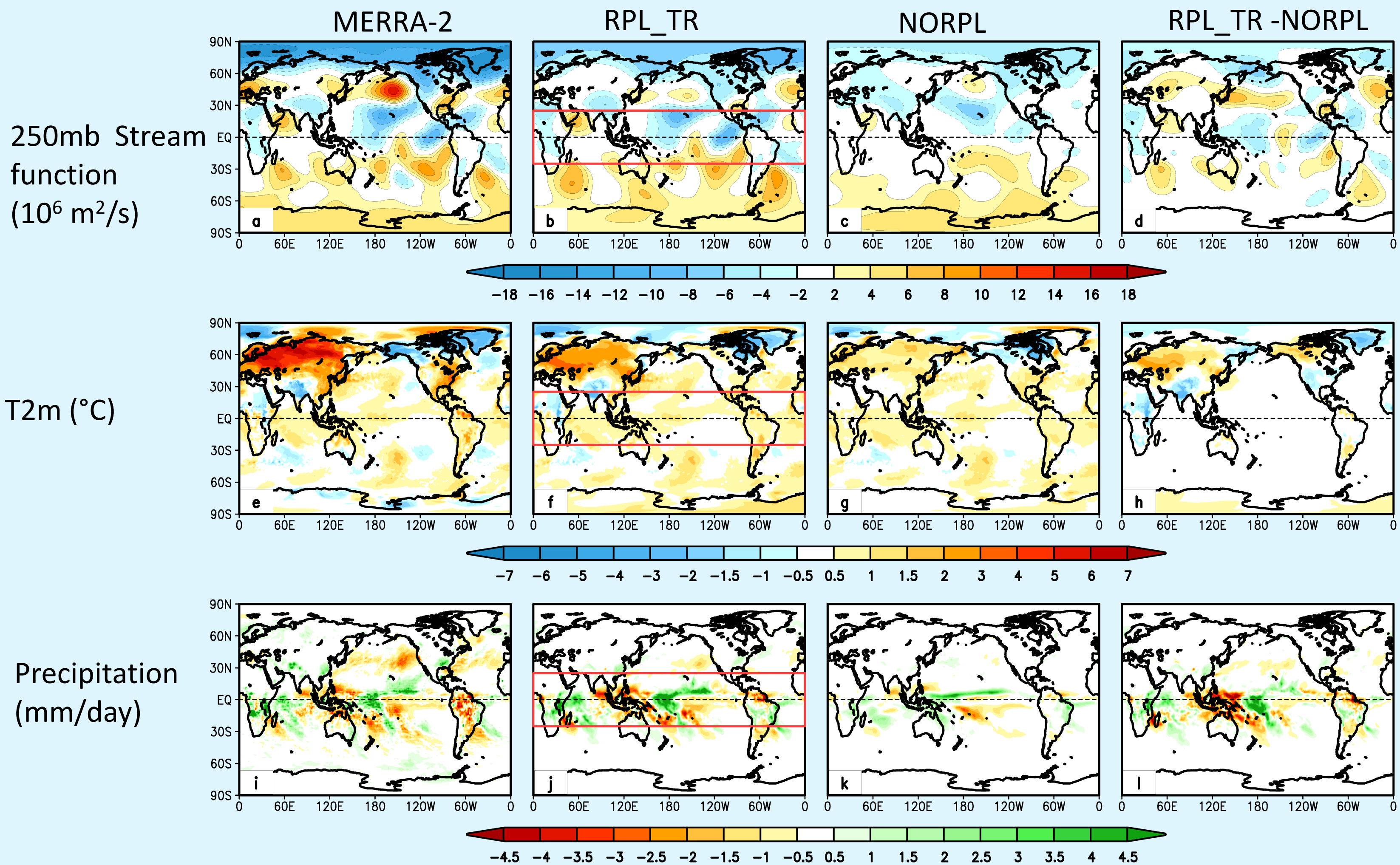
JFM 2020 SST anomalies and replay regions



ENSO:
at threshold of
a weak El Niño

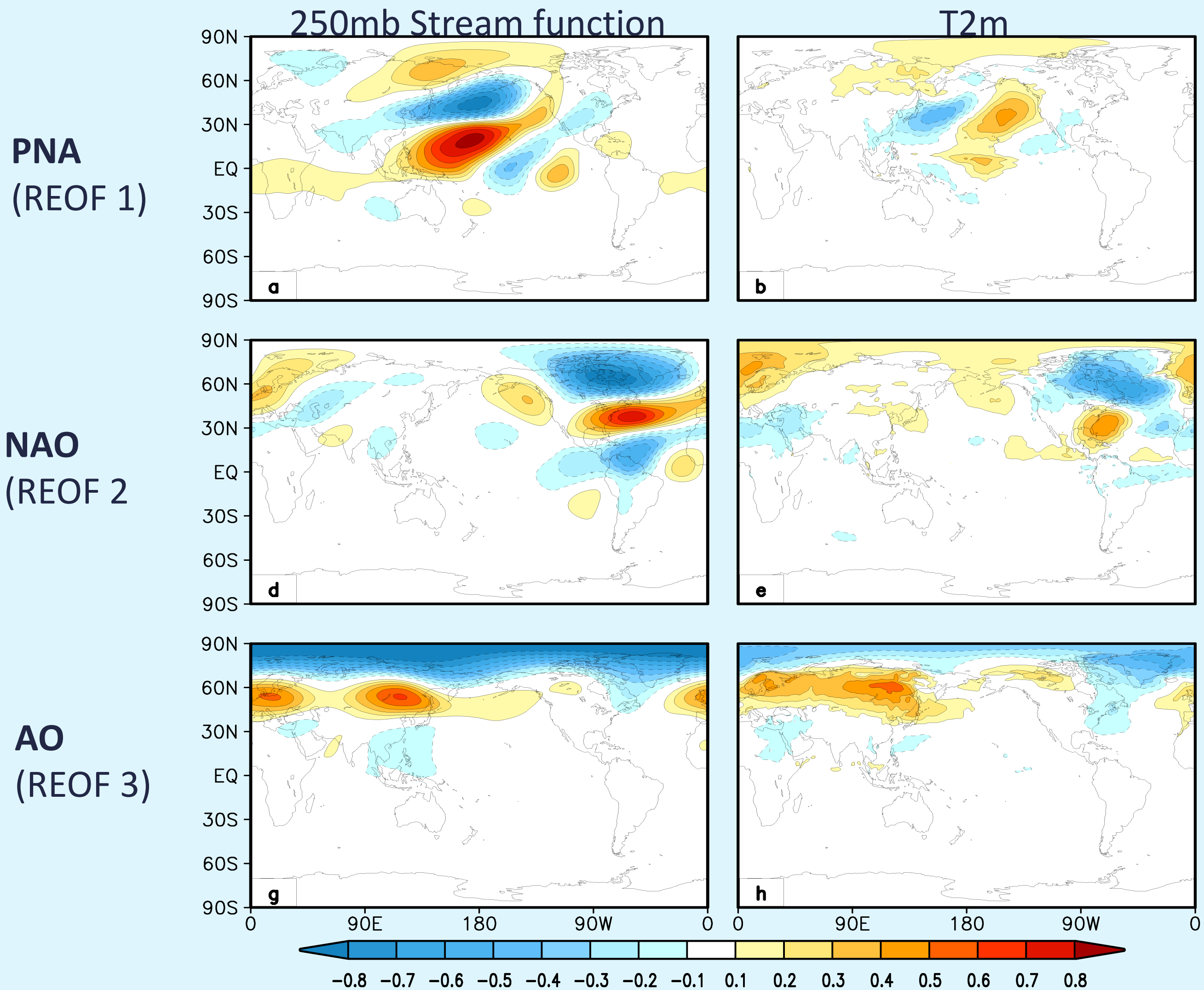
JFM 2020 Anomalies

(model results are averages of 90 ensemble members)

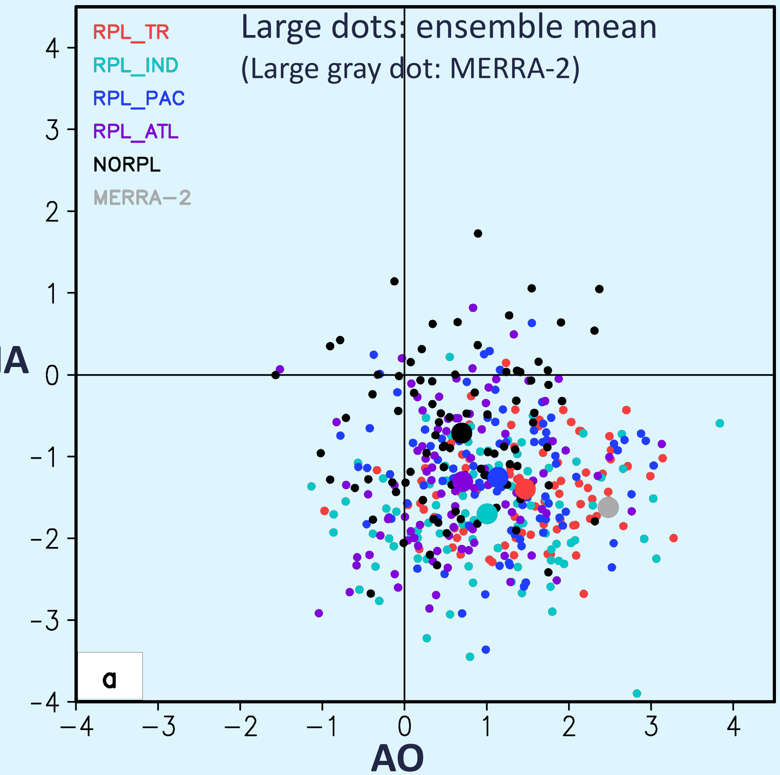


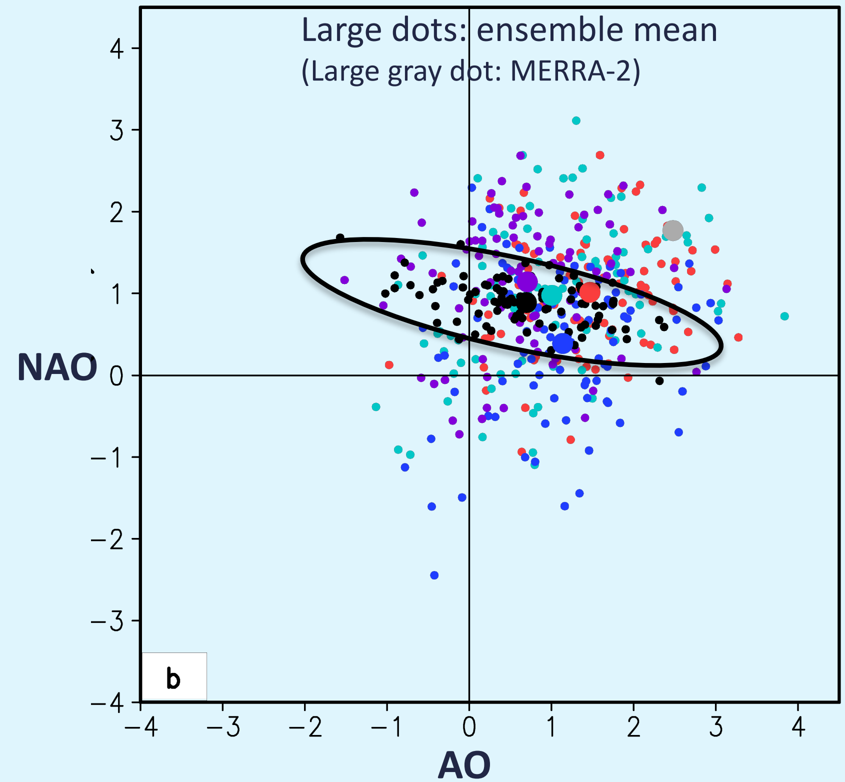
Correlations with the Leading Intra-ensemble REOFs of 250mb Stream function

(Based on monthly data for JFM 2020, 1350 monthly mean states)



2020 JFM





Probability of the model PCFs exceeding MERRA-2 values (**PEM**), for each experiment and leading REOF, for the 2020 JFM mean

Experiment	PNA (PCO = -1.62)	AO (PCO = 2.48)	NAO (PCO = 1.77)
NORPL	0.18	0.00	0.00
RPL_TR	0.36	0.11	0.12
RPL_PAC	0.31	0.10	0.03
RPL_IND	0.53	0.08	0.17
RPL_ATL	0.40	0.03	0.24

- Tropical replay increases the **PEM** of the AO and NAO from zero (i.e., an impossible event without replay) to about 10%.
- Tropical replay doubles the **PEM** for the PNA (0.18->0.36)
- Tropical replay increases the intra-ensemble variability of the NAO

March 2020 Anomalies

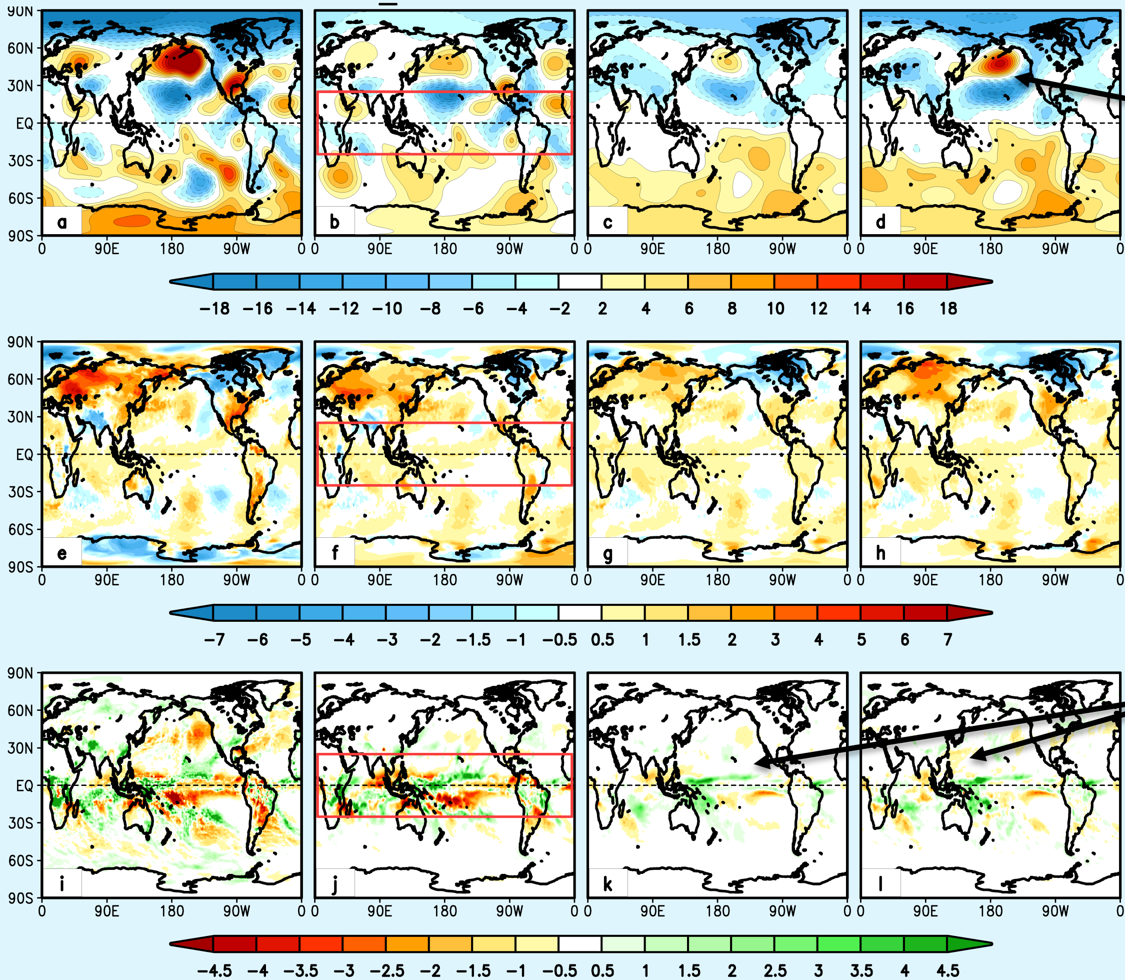
(model results are averages of 90 ensemble members)

MERRA-2 | RPL_TR | NORPL | NORPL_10 extreme (-PNA, AO)

250mb Stream function (10^6 m^2/s)

T2m (°C)

Precipitation (mm/day)



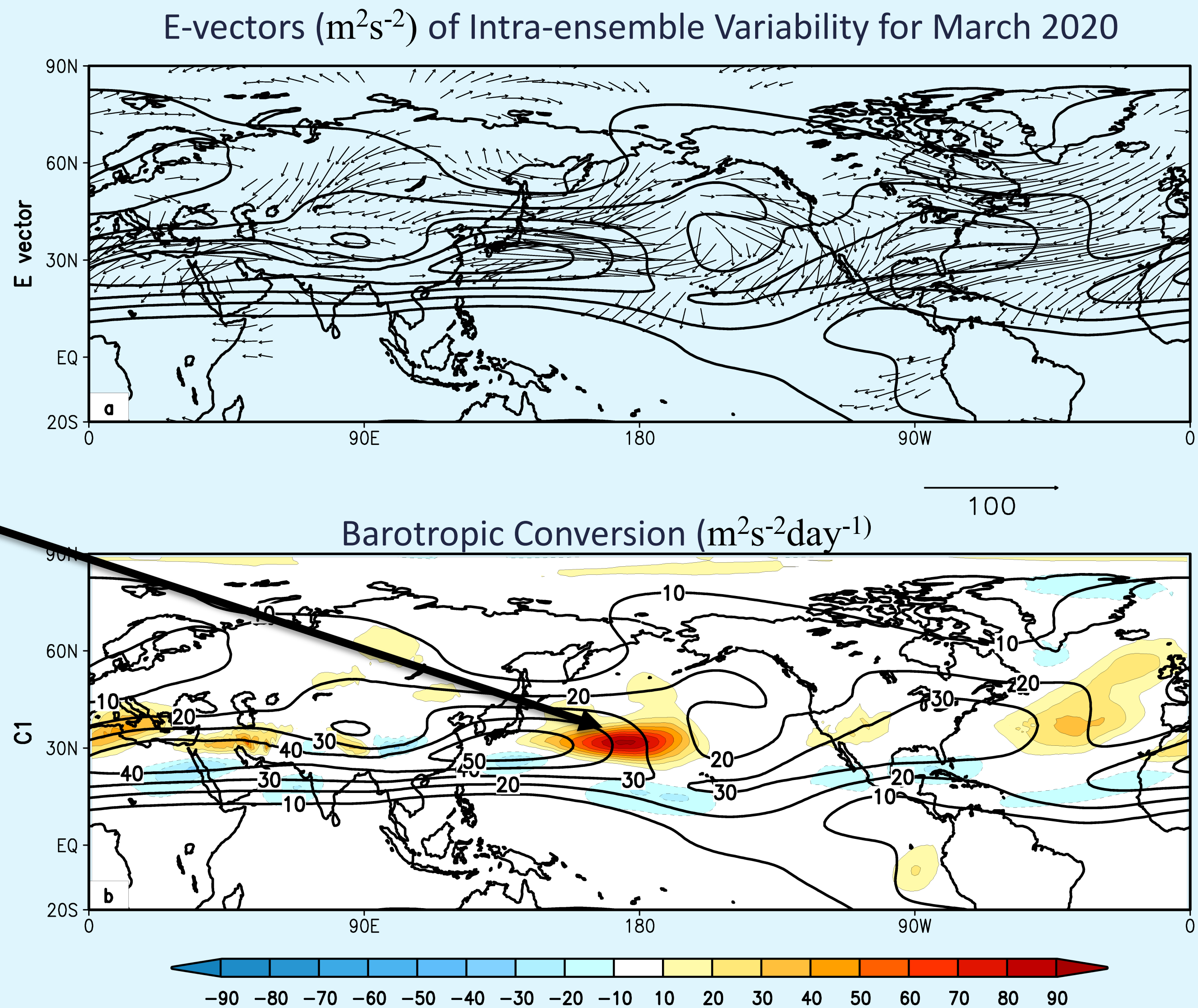
Extreme negative PNA

Can we say something about the mechanism that produces the extreme negative PNA?

Ensemble members with extreme negative PNA don't show a stronger tropical forcing

Motivated by Simmons et al. (1983) and Hoskins et al. (1983)

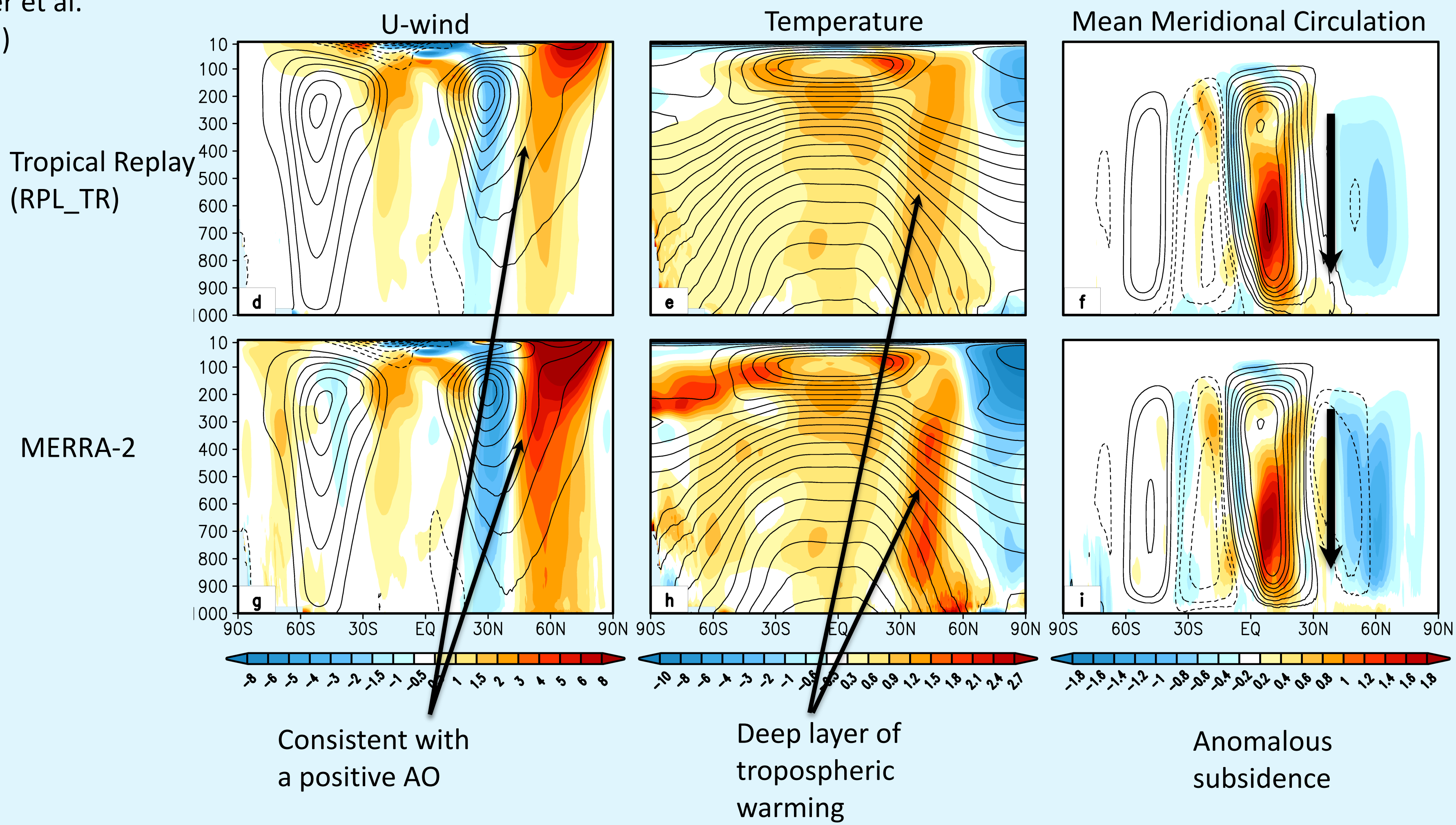
The PNA is extracting energy from the mean flow in the exit region of the North Pacific jet



What is maintaining the AO?

Analysis inspired by Seager et al. (2003)

2020 JFM Zonal Mean Anomalies

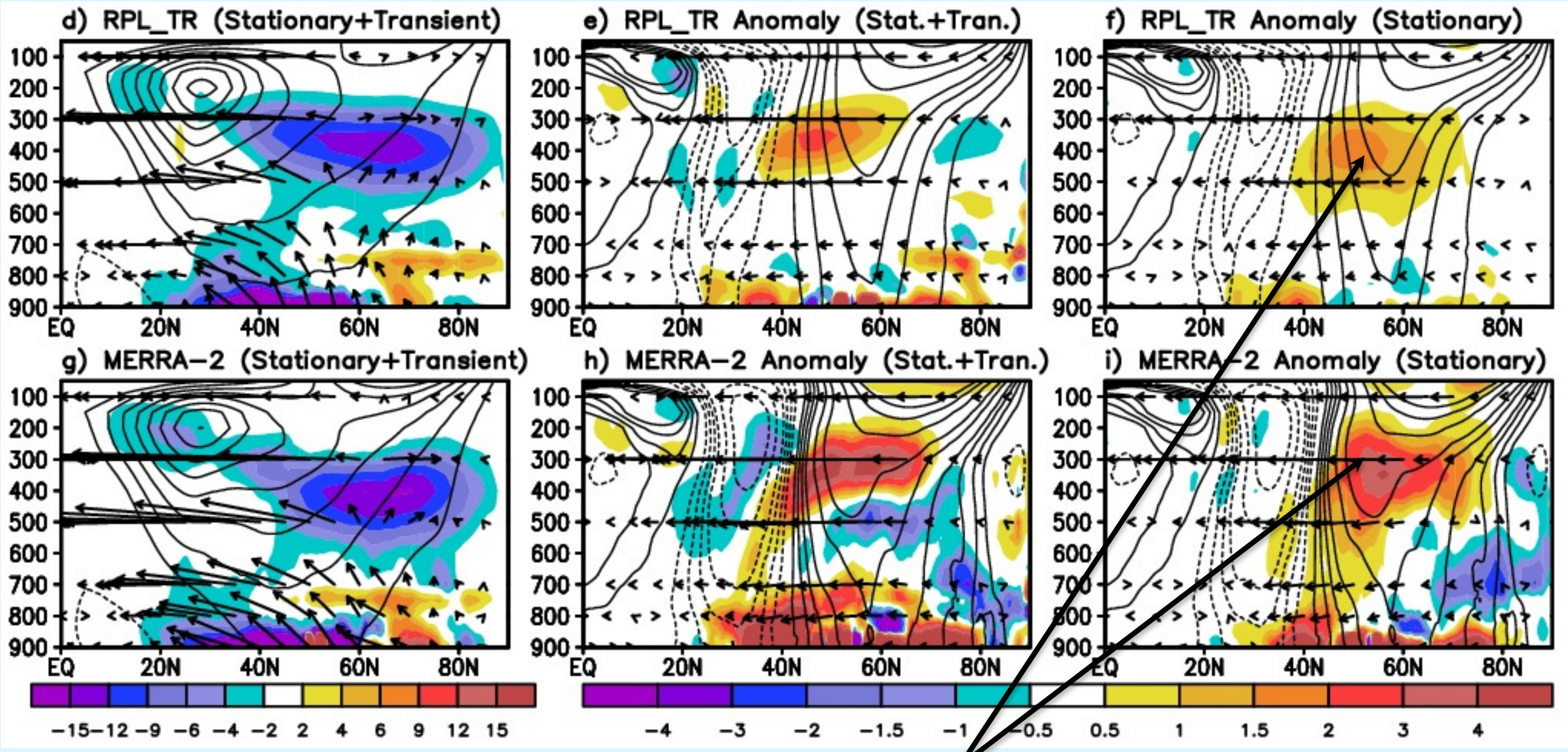


E-P flux (Edmon et al. 1980)

2020 JFM E-P flux (F) and divergence of F

Tropical Replay (RPL_TR)

MERRA-2



Positive AO: supported by stationary eddy-induced westerly acceleration

Anomalous MMC: atmosphere acting to balance the stationary eddy-induced westerly acceleration with a coriolis torque

Conclusions*

- An **extreme positive AO** played a major role in the 2020 JFM warming over Eurasia, with forcing from the tropical Pacific and Indian Ocean regions increasing the probability of such an extreme event occurring in the simulations from essentially zero (without replay) to 10%.

- An **extreme positive NAO** contributed to the JFM warming over Europe (especially in February) with forcing from the tropical Indian Ocean and Atlantic regions increasing the probability of such an extreme event occurring in the simulations from essentially zero (without replay) to roughly 20%, partly by increasing its intra-ensemble variability.

- The heat wave that developed over eastern North America during March was primarily associated with an **extreme negative PNA** that developed as an instability of the North Pacific jet, with tropical forcing providing support for a prolonged negative phase.

- **Anomalous stationary eddy forcing** (associated with the PNA and NAO) **acted to maintain the positive AO**. Those same eddies forced an anomalous Ferrel Cell, thereby creating **subsidence-induced warming of a deep layer of the troposphere**, roughly coinciding with the latitudes of surface warming.

*Schubert, S.D., Y. Chang, A.M. DeAngelis, R. D. Koster, Y.-K. Lim, and Hailan Wang, 2022: Exceptional Warmth in the Northern Hemisphere during January through March of 2020: The Roles of Unforced and Forced Modes of Atmospheric Variability. Accepted, J. Climate.